Measurements of vector-meson production with the ATLAS detector

Gabriella Pásztor[1]
for the ATLAS Collaboration

University of Geneva, Geneva, Switzerland

Abstract.
The inclusive J/ψ production cross-section and the fraction of J/ψ mesons produced in B-hadron decays in proton–proton collisions at $\sqrt{s} = 7$ TeV are presented. The measurements are based on data collected by the ATLAS detector at the Large Hadron Collider in 2010 and cover the J/ψ transverse momentum and rapidity values of $1 < p_{\mathrm{T}} < 70$ GeV and $|y| < 2.4$. The observation of a centrality dependent suppression of J/ψ production in the collisions of lead ions at $\sqrt{s_{NN}} = 2.76$ TeV is also reported.

INTRODUCTION

Heavy quarkonium hadro-production is not well understood being on the boundary of perturbative and non-perturbative regimes of Quantum Chromodynamics. At present no theoretical model can explain both the cross-section and the spin-alignment measurements at electron–positron, hadron–hadron and heavy ion collisions. The measurement of quarkonium production at the LHC allows to test the existing theoretical models of both quarkonium and b production in a new energy regime. Furthermore, the study of quarkonium production in heavy ion collisions can help to understand the properties of the hot, dense matter created in such collisions.

The ATLAS detector is described in [1]. The results described in this paper are based on the measurement of $J/\psi \to \mu\mu$ decays. Muons are reconstructed from tracks in the Inner Detector (ID) matched to a track (combined muon) or a segment in the Muon Spectrometer (MS). The trigger relied on the Minimum Bias Trigger Scintillators (MBTS) and on the muon trigger chambers. Due to the quickly changing luminosity conditions, the muon trigger p_{T} threshold was raised in several steps from 0 to 6 GeV.

The data sample collected in pp collisions in April–August 2010 amount to about 2.2 pb^{-1} and was used to measure the inclusive J/ψ production cross-section and the non-prompt fraction [2], i.e. the fraction of J/ψ mesons that originate from B-hadron decays:

$$f_B = \frac{\sigma(pp \to B + X \to J/\psi + X')}{\sigma(pp \xrightarrow{\text{inclusive}} J/\psi + X'')}. \tag{1}$$

During the lead ion run in November 2010, the trigger was based on the MBTS alone. The collected data corresponding to about 6.7 μb^{-1} were used to study the centrality dependence of J/ψ production [3].

[1] On leave of absence from KFKI Research Institute for Particle and Nuclear Physics, Budapest, Hungary.

J/ψ PRODUCTION IN PROTON-PROTON COLLISIONS

To identify $J/\psi \to \mu\mu$ decays in pp collisions, the event is required to have at least one reconstructed vertex with three tracks, each having at least six hits in the silicon strip and one in the pixel detector. Oppositely charged muon tracks are selected with $p_{\mathrm{T}}^{\mu} > 3$ GeV and $|\eta^{\mu}| < 2.5$ and refitted to a common vertex. For the inclusive measurement, only very loose vertex quality criteria are applied. For the B-fraction determination, where lifetime information is essential, the vertex-fit probability must exceed 0.005 and the two tracks must come from the same primary vertex. At least one of the muons is required to be a combined muon. One of the muons must match the trigger object.

The inclusive differential cross-section is calculated as

$$\frac{\mathrm{d}^2\sigma(J/\psi)}{\mathrm{d}p_{\mathrm{T}}\,\mathrm{d}y}\,Br(J/\psi \to \mu\mu) = \frac{N_{\mathrm{corr}}^{J/\psi}}{\mathscr{L}\,\Delta p_{\mathrm{T}}\,\Delta y}. \tag{2}$$

Here $N_{\mathrm{corr}}^{J/\psi}$ is the number of $J/\psi \to \mu\mu$ decays in a given $p_{\mathrm{T}} - y$ bin after background subtraction and correction for detector acceptance, selection efficiency, and bin migration. $\mathscr{L}$ is the integrated luminosity. Δp_{T} and Δy are the width of the p_{T} and y bins. To calculate $N_{\mathrm{corr}}^{J/\psi}$, a weight is defined for each event taking into account the kinematic acceptance, the bin migration, the efficiencies of ID tracking, offline muon reconstruction and trigger. The ID tracking and muon efficiencies are measured with a tag-and-probe (T&P) techniqe. The muon trigger efficiencies are extracted from a hybrid data-driven T&P and Monte Carlo (MC) scheme. The p_{T} and y resolutions used in the bin migration corrections are derived from data, as well. The sum of weights are fitted using a binned minimum-χ^2 method as a function of the reconstructed dimuon mass in bins of $p_{\mathrm{T}} - y$ accounting for the J/ψ and $\psi(2\mathrm{S})$ signal and the remaining background coming dominantly from fakes, muons from decay-in-flight of light hadrons and from heavy flavour hadron decays.

The resulting inclusive J/ψ production cross-sections are shown for $|y^{J/\psi}| < 0.75$ on the top left of Figure 1. The dominant systematic uncertainty is theoretical in nature: it is due to the unknown spin-alignment state of the produced J/ψ meson. The following sources of experimental systematic uncertainties are considered (in the approximate order of importance): muon reconstruction efficiency, muon trigger efficiency, luminosity, acceptance (including contributions from MC statistics, modelling of kinematic distributions, bin migration and modelling of QED final state radiation), fit procedure and J/ψ vertex finding efficiency. The experimental uncertainty is typically above 10%.

J/ψ from direct production or from the decays of heavier charmonium states (called together *prompt* production) can be separated from J/ψ produced in B-hadron decays (*non-prompt* production) using lifetime information. To extract the non-prompt fraction a simultaneous unbinned maximum likelihood fit of the dimuon reconstructed mass and the pseudo-proper time distributios is performed in bins of $p_{\mathrm{T}} - y$, with the pseudo-proper time defined from the transverse decay length L_{xy} as $\tau = L_{xy} \cdot m_{\mathrm{PDG}}^{J/\psi}/p_{\mathrm{T}}$. The measured non-prompt fraction is shown for $|y^{J/\psi}| < 0.75$ on the top right of Figure 1. Several important systematic uncertainties cancel in this fraction. The largest experimental uncertainty concerns the fit method itself.

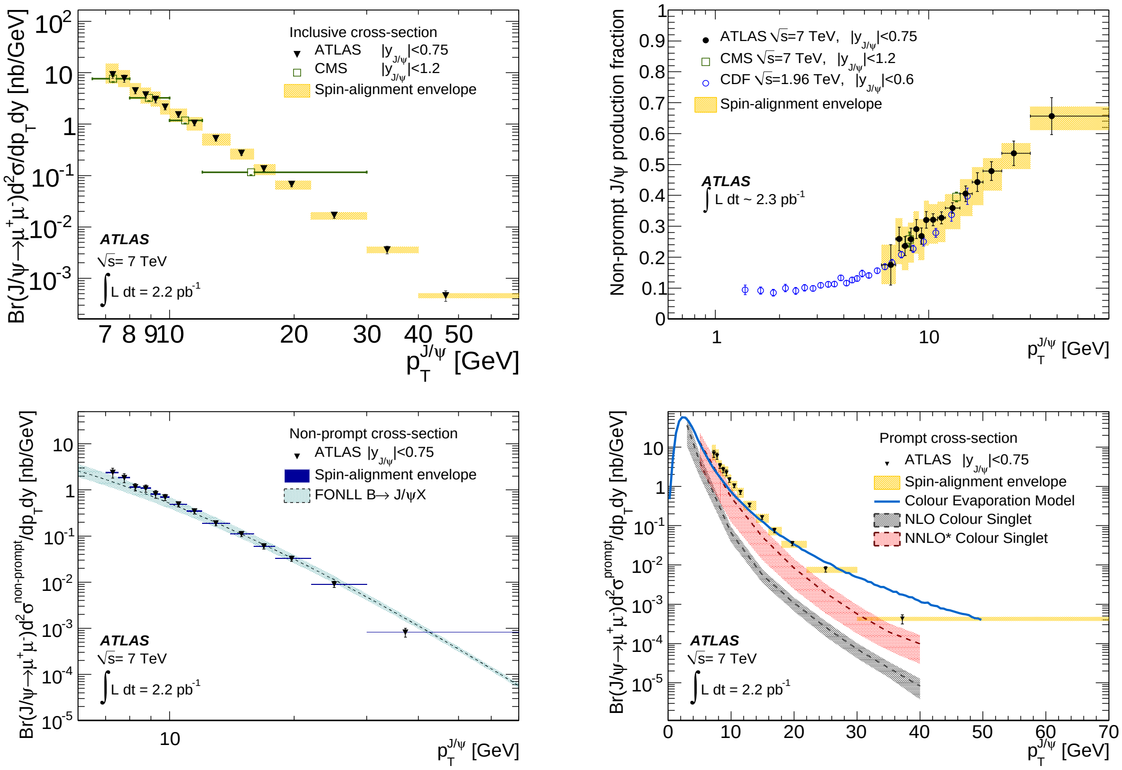

FIGURE 1. (top left) Inclusive J/ψ production cross-section, (top right) non-prompt to inclusive fraction, (bottom left) non-prompt production cross-section and (bottom right) prompt production cross-section as a function of the J/ψ transverse momentum, for the rapidity region $|y^{J/\psi}| < 0.75$. The error bars indicate the combined statistical and experimental systematic uncertainties (excluding the 3.4% luminosity uncertainty). Overlaid is a band representing the variation of the results under various spin alignment scenarios. Results for rapidity regions up to $|y^{J/\psi}| < 2.4$ are given in [2].

From these measurements, it is possible to extract the non-prompt and prompt cross-sections separately, shown on the bottom left and bottom right of Figure 1, respectively. The measured non-prompt cross-section is in excellent agreement with the FONLL v1.3.2 prediction [4]. The measured prompt cross-section is compared to the predictions of the Color Evaporation Model (CEM) and to the calculation of direct J/ψ production in the Color Singlet Model (CSM) at NLO and partial NNLO precisions (applying a 50% correction to take into account $\psi(2S)$ and χ_c feed-down). While CSM at NNLO* seems to describe the data better, it still deviates from the measurement especially at high p_T which might be attributed to missing higher order corrections.

J/ψ SUPPRESSION IN LEAD ION COLLISIONS

To select $J/\psi \to \mu\mu$ decays in lead–lead collisions, oppositely charged combined muons are selected with $p_T^{\mu} > 3$ GeV and $|\eta^{\mu}| < 2.5$ with stringent selection applied on the ID tracks: at least 9 silicon hits are required on each track, with no missing pixel

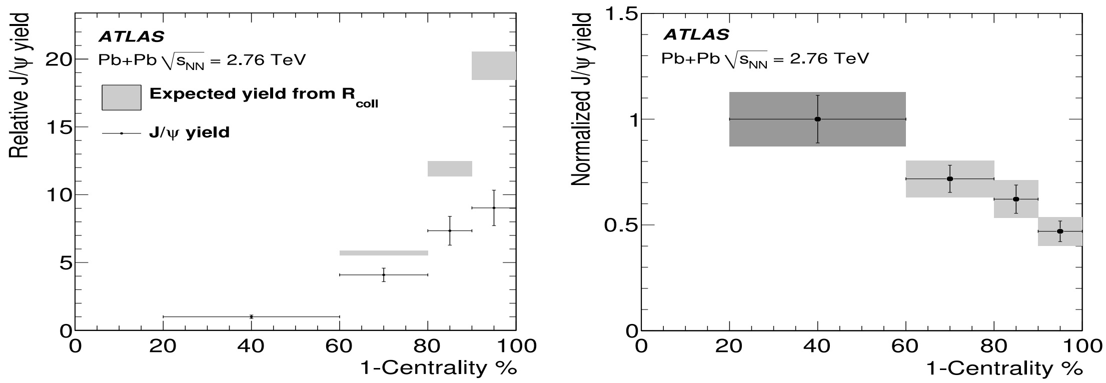

FIGURE 2. (left) Measured efficiency-corrected J/ψ yield and expected yield from the number of binary collisions, relative to the most peripheral bin. (right) The normalized J/ψ yield, calculated as the ratio of the measured and expected relative yields.

and maximum one missing strip detector hit allowed. The lead–lead collision centrality percentiles [7] are defined from the total transverse energy ($\Sigma E_T^{\rm FCal}$) measured in the Forward Calorimeter covering $3.2 < |\eta| < 4.9$. The most peripheral 20% of collisions are excluded, as they are affected by a large uncertainty on the predicted number of binary nucleon–nucleon collisions.

The $J/\psi \to \mu\mu$ reconstruction efficiency is obtained from PYTHIA+HIJING MC samples. The inefficiency increases with centrality by about 7% relative, from the most peripheral to the most central bin, primarily due to the increased occupancy in the ID. No centrality dependence is observed in the performance of the muon spectrometer. The number of $J/\psi \to \mu\mu$ decays comes from simple event counting, estimating the background from the sidebands with linear interpolation.

The measured J/ψ yield, corrected for efficiency and the width of the centrality bin, relative to the value obtained in the bin $40-80\%$ is shown on the left of Figure 2. The theoretical prediction from the number of binary nucleon-nucleon collisions taking into account the nuclear geometry is also shown. The dominant experimental systematic uncertainties come from the ID efficiency ($2.3-6.8\%$) and the signal extraction ($5.2-6.8\%$). The uncertainty on theoretical prediction reaches 5.3% for the most central bin. The ratio of the observed and expected relative yields is shown on the right of Figure 2. From these results the probability of a flat distribution, i.e. no centrality-dependent suppression, is only 0.11%.

REFERENCES

1. The ATLAS Collaboration, G. Aad et al., *JINST* **3**, S08003 (2008).
2. The ATLAS Collaboration, G. Aad et al., *Nucl. Phys.* **B850**, 387 (2011).
3. The ATLAS Collaboration, G. Aad et al., *Phys. Lett.* **B697**, 294–312 (2011).
4. M. Cacciari et al., *JHEP* **9805**, 007 (1998); *JHEP* **0103**, 006 (2001).
5. T. Ullrich et al., *Phys. Rept.* **462**, 125 (2008).
6. J. Lansberg, arXiv:1006.2750 [hep-ex]; S.J. Brodsky et al, *Phys. Rev.* **D81**, 051502 (2010); J. Lansberg et al., *Eur. Phys. J* **C61**, 693 (2009).
7. The ATLAS Collaboration, G. Aad et al., *Phys. Rev. Lett.* **105**, 252303 (2010).